Arch. Pharm. Res. **15**(1), 52-57 (1992)

Constituents of *Paulownia tomentosa* Stem(III): The Crystal Structure of Methyl 5-Hydroxy-dinaphtho [1,2-2′,3′] furan-7,12-dione-6-carboxylate

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(Received December 5, 1991)

Abstract □ The molecular structure of a natural compound was determined by single crystal X-ray diffraction analysis. The compound was isolated by methanol extraction and repeated chromatography from the stem of *Paulownia tomentosa*. Yellow prismatic crystals of the compound, which were recrystallized from tetrahydrofuran, are triclinic, with $a=7.310(6)$, $b=10.753(6)$, $c=11.586(5)$ Å, $\alpha=93.30(6)$, $\beta=105.62(10)$, $\gamma=109.49(7)°$, $D_x=1.514$, $D_m=1.51$ g/cm^3, space group $P\bar{1}$ and $Z=2$. The strucutre was solved by direct method, and refined by least-squares procedure to the final R-value of 0.032 for 1271 independent reflections ($F\leq 3\sigma(F)$). The compound is one of new furanquinone analogue. The molecule has a nearly planar conformation with an intramolecular hydrogen bond. In the crystal, the planar molecules are arranged as a parallel sheet-like pattern, and these stackings are stabilized by the O-H···O type intermolecular hydrogen bonds. The other intermolecular contacts appear to be the normal *van der Waals'* interactions.

Keywords □ Crystal structure, *Paulownia tomentosa*, furanquinone derivative, X-ray crystallography

It's an important and interesting field of the pharmaceutical sciences to evaluate and discover new biologically active compounds from herbal medicines. The cortex of *Paulownia tomentosa* is used as disinfectants or disorderants in Chinese medicine[1,2]. Several compounds such as catapol, syringin, iridoids, and lignans were reported as its ingradients[3-8].

In the series of investigation, we isolated a new furanquinone compound from the stem of *Paulownia tomentosa* by methanol extraction and repeated chromatography. The structure of the compound was difficult to identify by usual spectral methods such as NMR and/or IR etc. Hence its structure determination by crystallographic method was undertaken.

The present study deals with the precise structural analysis of the titled compound (Fig. 1) by single crystal X-ray diffraction technique. We were motivated to investigate the crystal structure of the compound to identify the structure of a newly discovered unknown compound, and to provide useful three-dimensional structural informations concerning its biological activities. The biological activities of the compound is now under investigation.

EXPERIMENTAL

The fractionation procedure of the compound was reported previously[9]. The compound was recrystallized by the slow evaporation method as yellow transparent prisms from a tetrahydrofuran solution at room temperature. The density was measured by the flotation in a potassium iodide solution.

A crystal of dimensions of $0.1\times0.3\times0.5$ mm was mounted on an Enraf-Nonius CAD4 diffractometer with graphite monochromated Mo$K\alpha$ radiations (50 kV, 32 mA). The lattice constants were determined by an auto-indexing routine with 21 reflections ($10\leq\theta\leq12$) which were centered from either a 10 min rotation photograph or a 'blind' search procedure.

Intensity data with range of $0\leq h\leq8$, $-12\leq k\leq12$, $-13\leq h\leq13$ were collected by ω-2θ scan technique ($1\leq\theta\leq20°$). Scan widths of $\Delta\omega=1.0+0.35\tan\theta$ and

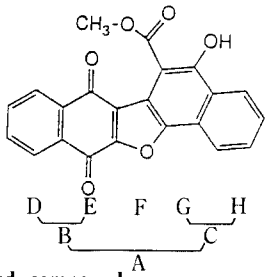

Fig. 1. The titled compound.
Capital letters mean the corresponding ring planes.

Table I. Crystal data

Methyl 5-hydroxy-dinaphtho[1,2-2',3']furan-7,12-dione-6-carboxylate	
Molecular formula; $C_{22}H_{12}O_6$	Mol. Wt.; 372.33
Yellow transparent prism,	Triclinic
$a = 7.310(6)$ Å	$\alpha = 93.3(1)°$
$b = 10.753(6)$ Å	$\beta = 105.6(1)°$
$c = 11.586(5)$ Å	$\gamma = 109.5(1)°$
Volume of unit cell; 815.9 Å^3	$F(000) = 384.0$
$D_m = 1.51$ g/cm^3	$D_x = 1.514$ g/cm^3
Space group; $P\bar{1}$	$Z = 2$

Table II. Fractional non-hydrogen atomic coordinates ($\times 10^4$) and thermal parameters ($\times 10^3$) with their estimated standard deviations in parentheses. The anisotropic temperature factors are expressed in the form of

$$exp(-2\pi^2(U_{11}a^{*2}h^2 + U_{22}b^{*2}k^2 + U_{33}c^{*2}l^2 + 2U_{12}a^*b^*hk + 2U_{13}a^*c^*hl + 2U_{23}b^*c^*kl))$$

Atom	*x/a*	*y/b*	*z/c*	U_{11}	U_{22}	U_{33}	U_{23}	U_{13}	U_{12}
O(1)	7334(3)	3001(2)	5574(2)	49(1)	38(1)	31(1)	9(1)	10(1)	17(1)
O(2)	8282(4)	3937(2)	8046(2)	93(2)	55(2)	39(1)	17(1)	21(1)	34(1)
O(3)	7017(3)	7063(2)	4717(2)	66(2)	55(1)	49(1)	22(1)	18(1)	34(1)
O(4)	5117(4)	2979(2)	687(2)	79(2)	52(2)	30(2)	8(1)	7(1)	28(1)
O(5)	8480(3)	6477(2)	2965(2)	50(1)	43(1)	52(1)	20(1)	12(1)	12(1)
O(6)	5989(4)	5600(2)	1222(2)	127(2)	57(2)	45(2)	18(1)	−12(2)	29(2)
C(1)	7744(4)	4288(3)	6018(3)	40(2)	32(2)	34(2)	6(2)	9(1)	12(2)
C(2)	7546(4)	5051(3)	5115(2)	32(2)	36(2)	35(2)	8(2)	10(1)	13(2)
C(3)	7661(4)	6422(3)	5447(3)	34(2)	42(2)	45(2)	14(2)	14(2)	15(2)
C(4)	8538(4)	6984(3)	6779(2)	36(2)	40(2)	44(2)	6(2)	15(2)	15(2)
C(5)	9049(5)	8341(3)	7136(3)	58(2)	43(2)	54(3)	8(2)	19(2)	19(2)
C(6)	9813(6)	8879(4)	8353(4)	69(3)	43(2)	67(3)	−6(2)	21(2)	14(2)
C(7)	10053(5)	8076(4)	9224(4)	65(3)	57(3)	48(3)	−6(2)	12(2)	18(2)
C(8)	9541(5)	6726(4)	8892(3)	55(2)	56(3)	44(2)	5(2)	12(2)	22(2)
C(9)	8796(4)	6167(3)	7664(3)	37(2)	41(2)	42(2)	5(2)	11(2)	14(2)
C(10)	8272(4)	4715(3)	7318(3)	44(2)	48(2)	37(2)	12(2)	12(2)	20(2)
C(11)	6863(4)	2933(3)	4337(2)	37(2)	42(2)	28(2)	9(2)	9(2)	15(2)
C(12)	6973(4)	4157(3)	3988(2)	32(2)	36(2)	33(2)	10(1)	10(1)	15(2)
C(13)	6467(4)	4229(3)	2713(2)	38(2)	38(2)	31(2)	12(2)	9(2)	17(2)
C(14)	5710(4)	3049(3)	1906(3)	43(2)	49(2)	29(2)	11(2)	9(2)	20(2)
C(15)	5582(4)	1780(3)	2294(3)	38(2)	38(2)	36(2)	7(2)	12(2)	16(2)
C(16)	4847(5)	593(3)	1461(3)	57(2)	49(3)	34(2)	5(2)	11(2)	21(2)
C(17)	4802(5)	−592(4)	1850(3)	62(2)	43(2)	48(3)	2(2)	16(2)	17(2)
C(18)	5495(5)	−639(3)	3091(3)	58(2)	38(2)	55(2)	14(2)	22(2)	18(2)
C(19)	6218(5)	500(3)	3929(3)	50(2)	43(2)	42(2)	10(2)	16(2)	17(2)
C(20)	6249(4)	1721(3)	3546(3)	35(2)	36(2)	37(2)	8(2)	11(2)	14(2)
C(21)	6896(5)	5489(3)	2228(3)	57(2)	50(2)	34(2)	11(2)	12(2)	28(2)
C(22)	9052(8)	7766(4)	2565(5)	82(3)	42(3)	80(3)	33(2)	32(3)	20(2)

a variable scan speed of 2-7°/min were chosen to assure $I > \sigma(I)$. Intensities of two reflections, (−4 1 2) and (4 −1 −2) were repeatedly monitored every 2 h during the data collection, and did not show any significant variations. The reflections were corrected for usual Lorentz and polarization effects, but not for absorptions ($\mu = 0.68$ cm^{-1}). Of all 1518 independent reflections, 247 reflections which had

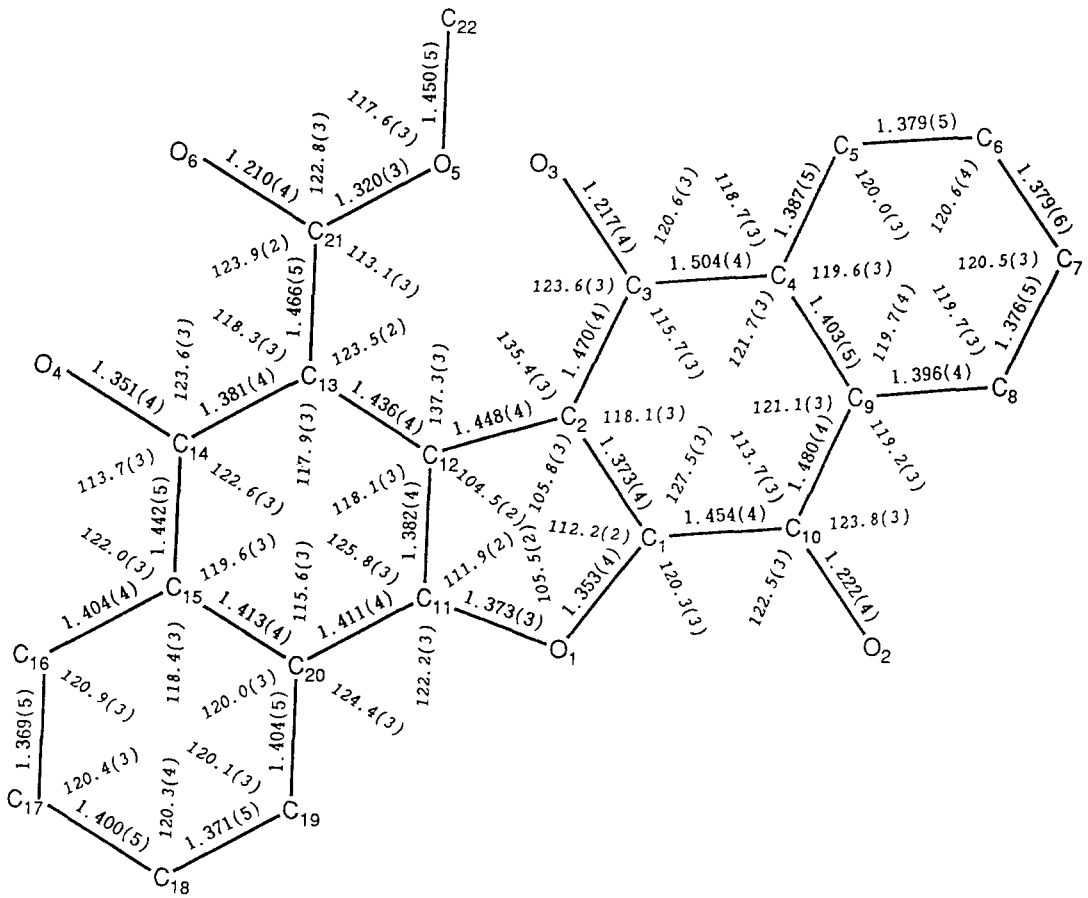

Fig. 2. The bond lengths(Å) and angles(°) of the compound with their estimated standard deviations in parentheses.

$F<3\sigma(F)$ were treated as unobserved. The space group was deduced as $P\bar{1}$ from the zero-moment statistics, and confirmed in the subsequent structure determination. The crystallographic data are listed in Table I.

The structure was solved by the random multiple-tangent-formula refinement method (*RANTAN* procedure) incorporated in *MULTAN84*[10] program. With the previous knowledge from the spectral analysis, a naphthalene group and a methoxy were used as randomly oriented group scattering model. E. values larger than 1.0 were used for phase generation, and the solution was obtained from the set having the highest combined figure of merit. All the 28 nonhydrogen atoms were appeared on the first E-map.

The structure was refined by full matrix least-squares procedure incorporated in *SHELX76*[11] with isotropic temperature factors to the R value of 0.105. Further refinement with anisotropic temperature factors reduced the R value to 0.067. A difference Fourier synthesis calculated at this stage revealed all the hydrogen atoms of the compound. Refinements including hydrogen atoms for 1271 reflections ($F\geq3\sigma(F)$) produced the final R value of 0.032 ($wR=$ 0.030, unit weight). In the final cycle the average and maximum shift/e.s.d. for the parameters are 0.027 and 0.209 for non-hydrogen atoms, and 0.088 and 0.615 for hydrogen atoms, respectively. The final difference map showed maximum electron density of 0.16 e/Å^3.

The final atomic parameters are listed in Table II and III, together with their estimated standard deviations. The observed and calculated structure factors are available upon request. All the calculations were carried out on a microVAX 3100/VMS

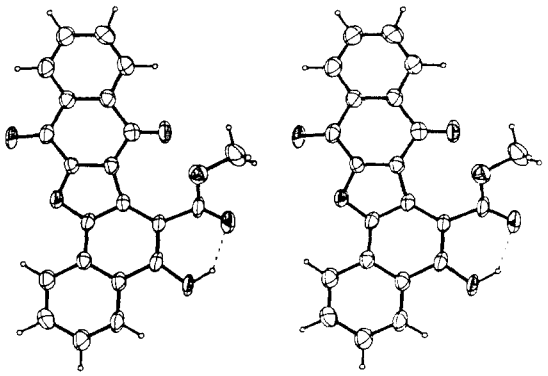

Fig. 3. The stereoscopic drawing of the compound. The thermal ellipsoids are drawn at the 50% probability level. The broken line indicates the intramolecular hydrogen bond.

system and an IBM personal computer at Seoul National University. The atomic scattering factors were taken from "International Tables for X-ray Crystallography"[12].

RESULTS AND DISCUSSION

The atomic numbering scheme, bond lengths and angles are shown in Fig. 2. All the molecular dimensions are in the chemically reasonable range[13]. The stereoscopic view of the molecule drawn by *ORTEP*[14] is presented in Fig. 3.

The compound is composed of five 5- or 6-membered rings, and the conjugated π electron system covers nearly all the molecule (yellow color, λ_{max}: 336, 450 nm). As a result, the whole molecule is planar (see Table IV). The unit rings (Plane A, B, C, D and E, see Fig. 1) of the molecule show good

Table III. Fractional hydrogen atomic coordinates and thermal parameter ($\times 10^3$) with their e.s.d's in parentheses. The isotropic temperature factors are expressed in the form of

$$exp(-8\pi^2 U \sin\theta/\lambda^2)$$

Atom	Bonded to	*x/a*	*y/b*	*z/c*	*U*
H(O4)	O(4)	501(6)	381(4)	46(4)	117(16)
H(5)	C(5)	884(4)	890(3)	647(3)	58(9)
H(6)	C(6)	1031(5)	988(4)	862(4)	75(11)
H(7)	C(7)	1065(5)	848(3)	1012(3)	70(10)
H(8)	C(8)	976(4)	615(3)	952(3)	59(10)
H(16)	C(16)	436(4)	62(3)	62(3)	40(9)
H(17)	C(17)	422(5)	−142(3)	125(3)	62(10)
H(18)	C(18)	545(5)	−151(3)	340(3)	64(10)
H(19)	C(19)	674(4)	52(2)	482(3)	36(8)
H(22-1)	C(22)	793(8)	783(5)	189(5)	159(23)
H(22-2)	C(22)	951(8)	842(5)	332(5)	164(24)
H(22-3)	C(22)	997(8)	789(5)	222(5)	152(26)

planarities themselves, and most planar ones are the most outside and least substituted rings (Plane A, E, comparison data not shown). The two 6-membered rings (Plane D, E) of naphthalene are slightly distorted each other, like the open wings of a butterfly, with dihedral angle of 3.0°.

The C(13)-C(21) bond can be rotated. Energetically, the most preferable conformation of the methylcarboxylate group seems to be perpendicular case to the ring plane because of the crowdings between oxygens (O(3) and/or O(4)). MMX energy approximation by *PCMODEL*[15] showed very steep and high rotation-energy-barriers (about 200 kcal/mole or more) at the crowding positions. In the crystal, however, the methylcarboxylate has a tendency to be more coplanar with the ring plane than the expec-

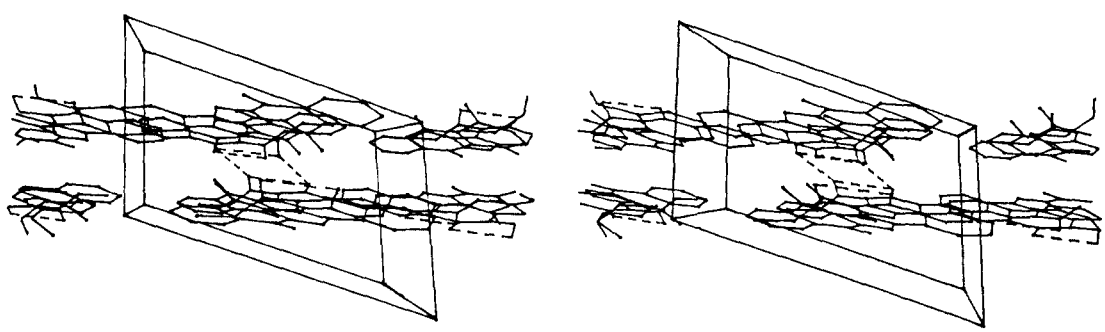

Fig. 4. The sheet-like packing of the compound (projected along c-axis).
The broken lines indicate the intra- and intermolecular hydrogen bonds.

Table IV. The equations of the least-squares planes of the planar regions of the compound, and the deviations of individual atoms from these planes(Å)
(For plane designations, see Fig. 1): *; Atoms used for the calculation of the equation

Equations:

Plane A: $0.9786X+0.2045Y+0.0250Z=3.0427$ ($\sum\Delta^2=0.1421$ Å^2)
Plane B: $0.9797X+0.2003Y+0.0010Z=2.8063$ ($\sum\Delta^2=0.0445$ Å^2)
Plane C: $0.9822X+0.1855Y-0.0291Z=2.8770$ ($\sum\Delta^2=0.0120$ Å^2)
Plane D: $0.9845X+0.1734Y-0.0248Z=2.4267$ ($\sum\Delta^2=0.0001$ Å^2)
Plane H: $0.9797X+0.1930Y-0.0554Z=2.7922$ ($\sum\Delta^2=0.0002$ Å^2)

Deviations from;

Atom	Plane A	Plane B	Plane C	Plane D	Plane H
C(1)	0.015*	−0.052*	0.261	−0.184	0.332
C(2)	−0.019*	−0.104*	0.192	−0.237	0.230
C(3)	0.200*	0.129*	0.458	0.044	0.494
C(4)	0.073*	0.039*	0.416	0.001*	0.488
C(5)	0.015*	−0.004*	0.405	0.004*	0.477
C(6)	−0.071*	−0.057*	0.398	−0.005*	0.502
C(7)	−0.084*	−0.050*	0.418	−0.001*	0.556
C(8)	−0.016*	0.002*	0.440	0.006*	0.578
C(9)	0.050*	0.034*	0.426	−0.007*	0.531
C(10)	0.107*	0.076*	0.435	−0.014	0.541
C(11)	−0.080*	−0.196	0.044*	−0.406	0.076
C(12)	−0.092*	−0.211	0.037*	−0.396	0.048
C(13)	−0.121*	−0.273	−0.062*	−0.485	−0.090
C(14)	−0.004*	−0.181	−0.013*	−0.445	−0.057
C(15)	0.028*	−0.146	0.015*	−0.436	−0.007*
C(16)	0.121*	−0.079	0.038*	−0.422	0.001*
C(17)	0.105*	−0.090	0.020*	−0.458	0.004*
C(18)	−0.007*	−0.171	−0.024*	−0.511	−0.002*
C(19)	−0.010*	−0.234	−0.044*	−0.523	−0.005*
C(20)	−0.018*	−0.205	−0.008*	−0.468	0.010*
C(21)	−0.399	−0.558	−0.343	−0.747	−0.396
C(22)	−1.508*	−1.649	−1.391	−1.772	−1.449
O(1)	−0.018*	−0.101	0.178	−0.280	0.246
O(2)	0.217	0.202	0.570	0.108	0.705
O(3)	0.524	0.438	0.755	0.355	0.762
O(4)	0.027	−0.182	−0.052	−0.477	−0.132
O(5)	−1.159	−1.295	−1.044	−1.443	−1.080
O(6)	−0.051	−0.235	−0.048	−0.443	−0.133

Dihedral angles between;

Plane	A and B 1.4°	A and C 3.3°	
	A and D 3.4°	A and H 4.7°	
	B and C 1.9°	B and D 2.2°	
	B and H 3.3°	C and D 0.7°	
	C and H 1.6°	D and H 2.1°	

ted (Table V, see also Fig. 3). This is thought to be due to the formation of an intramolecular hydrogen bond (O(4)-H···O(6), 2.669 Å).

Fig. 4 shows the stereoscopic packing diagram of the compound. In the crystal, the planar molecules are stacked as a parallel sheet-like pattern. Here again, the O(4)-H interacts with the O(6) at (1−x, 1−y, −z) to yield weak intermolecular hydrogen

Table V. Torsion angles (°) around single bonds

H(O4)-O(4)-C(14)-C(13)	12.5	O(5)-C(21)-C(13)-C(12)	27.7
H(O4)-O(4)-C(14)-C(15)	170.6	O(6)-C(21)-C(13)-C(12)	157.1
C(22)-O(5)-C(21)-O(6)	4.0	O(6)-C(21)-C(13)-C(14)	29.2
C(22)-O(5)-C(21)-C(13)	175.3		

bonds (2.852 Å). The other intermolecular contacts appeared to be the normal *van der Waals'* interactions.

ACKNOWLEDGEMENT

This work was supported in part by a research grant from S.N.U. Developmental Funds and Daewoo Academic Foundation in 1991.

Authors thank Dr. Sangsoo Kim, Lucky Ltd. R & D Center. Biotech., for the kindful help in the data collection.

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